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Effects of 20-min audio-visual stimulation (AVS) at dominant alpha frequency and twice dominant alpha frequency on the cortical EEG

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Abstract

The effects of audio-visual stimulation at the dominant alpha frequency and twice dominant alpha frequency on the EEG were investigated. An eyes-closed baseline EEG determined each subject's dominant alpha frequency. Subjects were stimulated at their dominant alpha frequency and at twice dominant alpha frequency for 20 min on two occasions. A 30-min post-session eyes-closed EEG was recorded after each session. Power data were analyzed for 19 locations in six bandpasses using repeated-measures ANOVAs and appropriate post-hoc tests. Alpha stimulation significantly increased power over baseline levels in the delta 1, delta 2, theta, beta 1 and beta 2, with significant effects remaining 30 min later in beta 1. Twice alpha stimulation significantly increased theta, beta 1 and beta 2 power over baseline levels, with significant effects remaining 30 min later in theta, alpha, beta 1 and beta 2. © 1999 Elsevier Science B.V. All rights reserved.

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The effect of external stimulation, particularly photic stimulation, on the cortical electroencephalograph (EEG) has been the object of several studies since the early 1930s (Adrian and Matthews, 1934; Walter and Walter, 1949; Townsend et al., 1975; Pigeau and Frame, 1992). During the 1950s and 1960s, researchers became interested in using both visual and auditory rhythmic stimulation as a means of inducing relaxation and hypnosis (see Morse, 1993 for a review). More recently, the use of devices that use either light, sound, or both light and sound together, presented at specified frequencies, have been explored as a mechanism to 'drive' the EEG to-

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wards certain frequencies. These devices provide audio-visual stimulation, abbreviated as AVS. AVS has been reported as an effective method to relieve dental anxiety (Morse, 1993), to induce hypnagogic states (Dieter and Weinstein, 1995), and as a tool to help relieve tension headaches (Solomon, 1985) and migraine headaches (Anderson, 1989). AVS may alleviate the cognitive dysfunctions associated with closed head injury (Montgomery et al., 1994), and damage from aneurysms and strokes (Russell, 1997). Significant improvement in cognitive and behavioral functioning, related to the number of AVS sessions, has been reported for learning-disabled boys (Carter and Russell, 1993). Finally, AVS may be useful for the clinical application of neurofeedback therapy, serving as an adjunct method for priming desired cortical frequencies (Patrick, 1996).

In light of the recent clinical applications of AVS, it is important to develop a more thorough understanding of AVS effects on cortical activity. Earlier experimental studies of AVS had mainly focused on the properties of the photic driving response, and were directed towards investigating alpha activity of the occipital regions. However, several recent studies have suggested AVS has a more diffuse effect on the cortical EEG than earlier suspected. Using low-frequency theta AVS, Dieter and Weinstein (1995) described significant reduction in mean activity (an increase of delta and theta activity) in frontal, central and parietal regions, in addition to occipital regions. Brauchli et al. (1995) found a reduction in alpha and theta spectral power during AVS utilizing variable and fixed frequency programs. Additionally, not all subjects produce an alpha driving response to photic stimulation. Kawaguchi et al. (1993), reported one-half of their subjects did not produce a photic driving response within the alpha bandpass to fixed-frequency, repetitive stroboscopic flashes ranging from 5 to 16 Hz. Rosenfeld et al. (1997) reported no significant long-term group effects of alpha stimulation (10 Hz) on alpha with nine participants. Further division of their participants into low- and high-baseline alpha groups indicated high-baseline alpha participants showed either no AVS effects or prolonged AVS effects after 10 Hz stimulation, while low-baseline alpha participants showed transient AVS effects.

A limitation of all EEG studies to date using photic or audio-visual stimulation has been the examination of a restrictive number of scalp locations and/or frequencies. There have been no systematic studies of AVS on the 19 locations of the 10/20 International EEG locations over the entire range of EEG frequencies from <1 to 32 Hz. This preliminary study was designed to specifically address the effect of AVS at an individual's dominant alpha frequency and twice the dominant alpha frequency across 19 locations and over the range of EEG frequencies from <1 to 32 Hz, including post-session effects.

Thirteen participants (seven male and six female) were recruited from the undergraduate and graduate populations of the University of Tennessee, Knoxville. Participants ranged in age from 20 to 30 years, with a mean of 25.5 years. All participants reported no previous history of epilepsy, learning disabilities, attention deficit disorder, or mental illnesses during personal screening interviews. Participants self-reported that they were free of medication use during the study. The protocol for this study was approved by the University of Tennessee IRB.

Audio-visual stimulation was provided by a Polysync Pro (Synetic Systems) device. This unit consisted of headphones and a pair of 'photoscopic' glasses that were connected to a small, portable unit that was programmed to provide specified levels of visual and auditory stimulation. The glasses had eight light-emitting diodes (LEDs), four per side, arranged in a cross pattern. The LEDs were situated approximately 1.5 cm from the eyes, and emitted red light at 0.166 cd power at the frequencies employed. Audio stimulation consisted of a cycled tone with a frequency of 185 Hz, presented to both ears simultaneously, with a duty cycle of 50% and a loudness level of approximately 77 dB (A scale) for the alpha condition and 81 dB (A scale) for the beta condition. Both auditory and visual stimulation were sinusoidally modulated to eliminate possible stimulation effects due to harmonic frequencies. The

Polysync Pro equipment was tested for and did not produce any detectable electrical interference in our EEG recordings.

A quantitative referential (monopolar montage) EEG was recorded from 19 electrodes following the International 10/20 system for electrode placement, with linked earlobe references. All electrode impedances were below 5 kΩ. Recordings were made using an electrode cap (Electro Cap Inc.). Raw EEG was amplified by 19 matched 7P511 pre-amplifiers (Grass Instrument Co.), with bandpass filters set to 0.5–100 Hz. A BMSI 12-bit A to D converter digitized the outputs of the amplifiers. Rhythm software (Stellate Systems) was employed to record the raw EEG. The sampling rate was set at 128 samples per second. Signal aliasing was eliminated by the use of a 16-point FIR (finite impulse response) filter, with a sharp low-pass cutoff set at 64 Hz and higher.

The EEG was analyzed off-line on a Pentium 133 processor using Rhythm software to provide power data. This analysis employs Hanning windowing and cosine tapering of each selected 4-s epoch. Eye-blinks, large eye movements, and all observable muscle artifacts were removed prior to analysis by a visual review of the EEG records by the first author. Artifact rejection was reevaluated and confirmed by the other authors.

The 13 participants came to the laboratory on two different occasions for AVS sessions. These sessions were at least 2 weeks apart to minimize carry-over effects. The procedure was the same for both stimulation sessions. Participants were seated upright in a plastic chair located in a sound-attenuated, dimly lit room for the EEG recordings. The headphones and glasses were placed over the electrode cap. All participants had an eyes-closed baseline EEG recorded for 4 min at the beginning of the session. This baseline recording was analyzed to determine each subject's dominant alpha frequency, defined as the peak power between 8 and 12 Hz at locations Pz and P4 as measured by power spectral analysis and Fast Fourier transformation, rounded to the nearest 0.5 Hz. Participants were then provided AVS for 20 min, with EEG recording occurring simultaneously. For the alpha stimulation condition, each participant was stimulated at their dominant alpha frequency. During the beta stimulation condition each participant received AVS at twice their dominant alpha frequency. Participants were instructed to close their eyes and relax during the 20-min AVS. Thirty minutes after the stimulation session, a post-session eyes-closed EEG was recorded for 5 min. The presentation of the AVS condition was counter-balanced; during the first AVS session six of the participants experienced alpha stimulation and seven experienced beta stimulation and vice versa for the second session.

EEG data were analyzed to provide power data for the 19 recording locations in each of six bandpasses (delta 1, 0.75–2 Hz; delta 2, 2–4 Hz; theta, 4–8 Hz; alpha, 8–12 Hz; beta 1, 12–21 Hz; and beta 2, 21–31 Hz). Each 20-min AVS condition was analyzed in four 5-min blocks (0–5 min, 5–10 min, 10–15 min, and 15–20 min) to examine changes over the course of stimulation. The post measure was a 5-min EEG recording 30 min after the AVS session. Thus, there were six power measures in the study: baseline, 5 min, 10 min, 15 min, 20 min, and post. All EEG data were log-transformed [$\log(x)$] to correct for skewed distributions. Histograms of log-transformed data were normally distributed.

Due to the exploratory nature of the study, we were interested in the effect of AVS on a large number of variables. To reduce the data to a more manageable size, we conducted a one-way repeated-measure ANOVA separately for each location within a bandpass, with time (baseline, 5 min, 10 min, 15 min, 20 min, and post) as the within-subject factor using SPSS (version 8) software. These analyses indicated which locations within a particular bandpass had significant changes in power over time. Mauchly's test was utilized to check for sphericity of the data. If sphericity was not violated, the more powerful univariate repeated measures using the split plot approach was used to test significance [degrees of freedom (d.f.) = 5,60]. For violation of sphericity, the multivariate approach to repeated measures was used (d.f. = 5,8).

There were no order effects of stimulation session, as would be expected with the AVS sessions

conducted at least 2 weeks apart. All alpha stimulation data were grouped for analysis, as were all beta stimulation data. For the alpha stimulation condition, the ANOVA analyses indicated a total of 23 significant locations with $P < 0.05$. The locations, by bandpass, were as follows: delta 1: T3, C3, Cz, C4; delta 2: F3, C3, Fz, Cz; theta: F4, O2, T6; alpha: no significant ANOVA results; beta 1: F7, Fp1, F3, Fz, F4, F8; beta 2: T5, F3, P3, Fz, Cz[1]. For the beta stimulation condition, the ANOVA analyses indicated a total of 36 significant locations with $P < 0.05$. The locations, by bandpass, were as follows: delta 1: F7, F3, Fp2, F4, T4; delta 2: no significant ANOVA results; theta: T3, T5, Fp1, F4, C4, P4, F8, T4, T6; alpha: C3, C4, F8; beta 1: F7, T5, Fp1, F3, C3, O1, Fz, Cz, Pz, Fp2, F4, C4; beta 2: T3, C3, P3, O1, Fz, Cz, Pz.

We recognize the large number of analyses conducted with these data increases the chances of Type I error. With 114 ANOVAs conducted for each AVS condition, we can expect up to six locations to be indicated by chance as showing significance for each condition with an alpha level equal to 0.05 ($114 \times 0.05 = 5.7$). However, we believe that the importance of understanding the effects of AVS over the entire range of EEG frequencies for < 1–32 Hz and across the 19 locations of the 10/20 International EEG classification system justifies examining such a large number of variables. Previous studies were limited in scope in this regard, with frontal locations and low frequency (< 7 Hz) bandpasses virtually ignored by researchers. It is important to keep in mind these are preliminary findings that need to be confirmed by further research.

Five paired difference *t*-tests compared the baseline mean FFT output to each of the stimulation (first 5 min, second 5 min, third 5 min, and last 5 min of AVS) and post mean FFT outputs for each significant location indicated by the ANOVA analyses. A Bonferroni adjusted probability level of $P < 0.05$ ($0.05/5 = 0.01$) was used to define significance for each of these pairwise post hoc comparisons. Locations indicating significant changes from baseline power during and after the 20-min AVS session are presented in Fig. 1 for the alpha AVS condition and in Fig. 2 for the beta AVS condition.

The overall effects of AVS on the cortical EEG as presented in this study indicated stimulation in the frequency ranges of 8–12 Hz did not have a significant effect on the corresponding alpha activity of the cortex. Earlier studies had indicated individual differences in the photic driving response (Kawaguchi et al., 1993; Rosenfeld et al., 1997), and it had been suggested that these differences may be due to a suppression of the natural alpha rhythm when exposed to stimulation at a frequency other than an individual's spontaneous alpha (Townsend et al., 1975; Rosenfeld et al., 1997), which is why we chose to provide AVS at each subject's dominant alpha frequency. Further research is necessary, possibly making use of a denser electrode array or delineating participants as high or low alpha producers, to help determine the individual differences involved in response to alpha AVS.

Stimulation at the dominant alpha frequency did affect bandpasses other than alpha, with the most lasting effect on beta 1 (13–21 Hz). There were also within-session increases of low frequency activity at central locations, increases of theta activity (4–8 Hz), and increases of beta 2 activity (21–32 Hz) with alpha AVS. This paradoxical increase of central activity within low frequency (0.5–4 Hz) bandpasses along with an increase of frontal beta activity during extended sessions of AVS has also been reported by Dieter and Weinstein (1995), although these researchers used low-frequency preprogrammed stimulation designed to increase theta activity.

Beta AVS (stimulation at twice the dominant alpha frequency) increased within session beta 1 (13–21 Hz) activity. Twelve of the 19 locations within the beta 1 bandpass had significant increases in power during the beta AVS session. Ten of these locations showed significant lasting effects, with increases of power ranging from 6 to 11% remaining 30 min after beta AVS had ceased. To a lesser degree, beta AVS had significant

[1]A detailed presentation of *F*-values, means, standard deviations and *t*-scores can be obtained from the authors upon request.

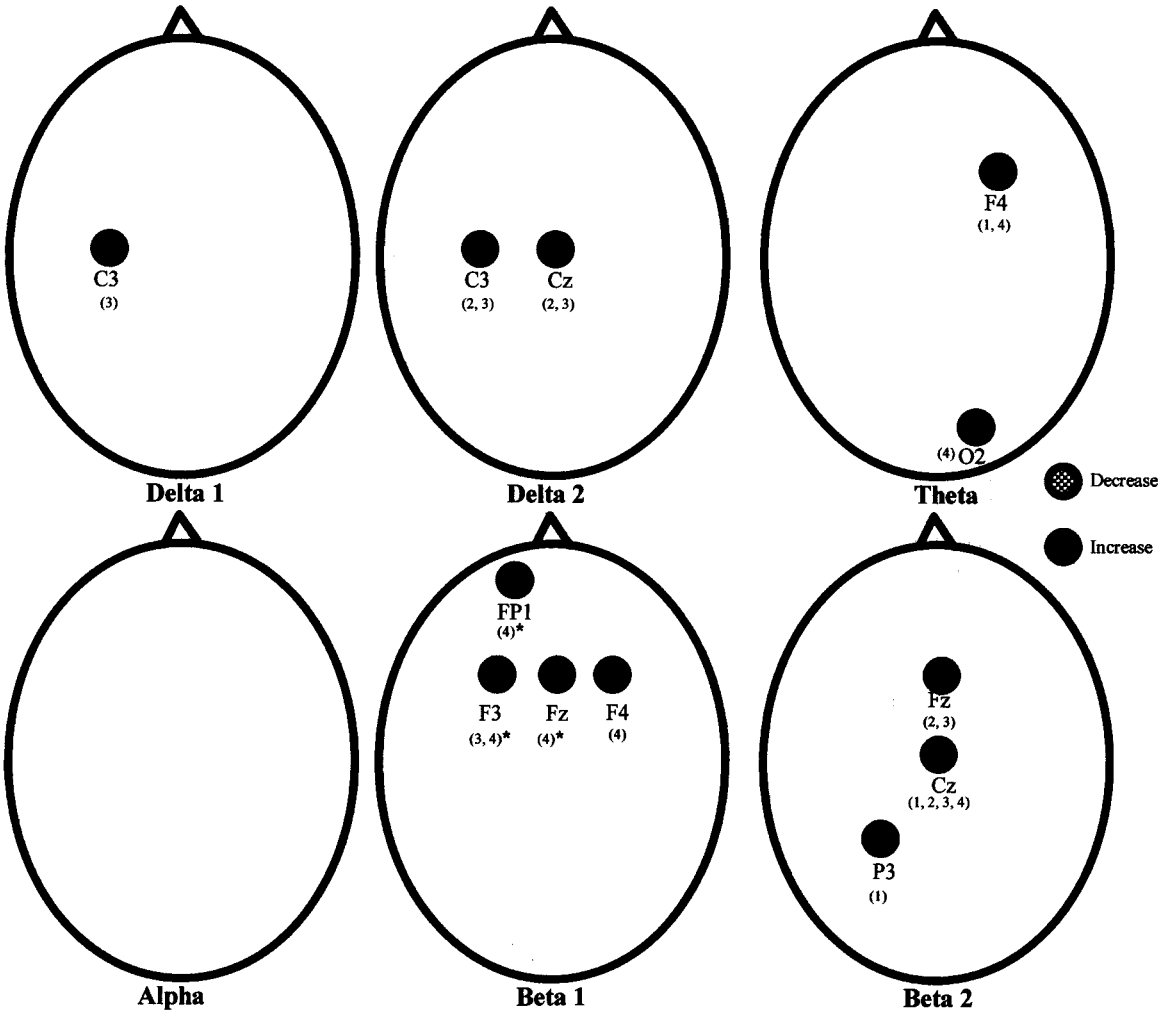

Fig. 1. Significant changes from baseline EEG activity during the alpha AVS condition. Numbers indicate time period of significance (1 = first 5 min of AVS, 2 = second 5 min, 3 = third 5 min, 4 = last 5 min). Asterisks indicate significant changes remaining 20 min after the AVS session had ended. Correction for multiple comparisons: Bonferroni.

within-session and post-session effects on beta 2, with seven locations showing significant within-session increases and four locations (C3, P3, Fz, and Cz) showing significant post-session increases. Beta AVS also significantly increased within-session theta power in mainly right hemisphere locations and showed post-session increases at T5 and T6, which was unexpected. Additionally, there were significant decreases in power at frontal locations within the delta 1 bandpass.

It may be suggested that these results are due to alpha desynchronization. However, there are several reasons why this possibility is not supported by the data presented in this study. First, no significant effects of any kind, neither decreases nor increases, occurred within the alpha bandpass during either AVS session. Secondly, if alpha blocking did occur, the effect would be expected to habituate over time, particularly in light of the 20-min AVS sessions. This did not happen. Furthermore, none of the significant

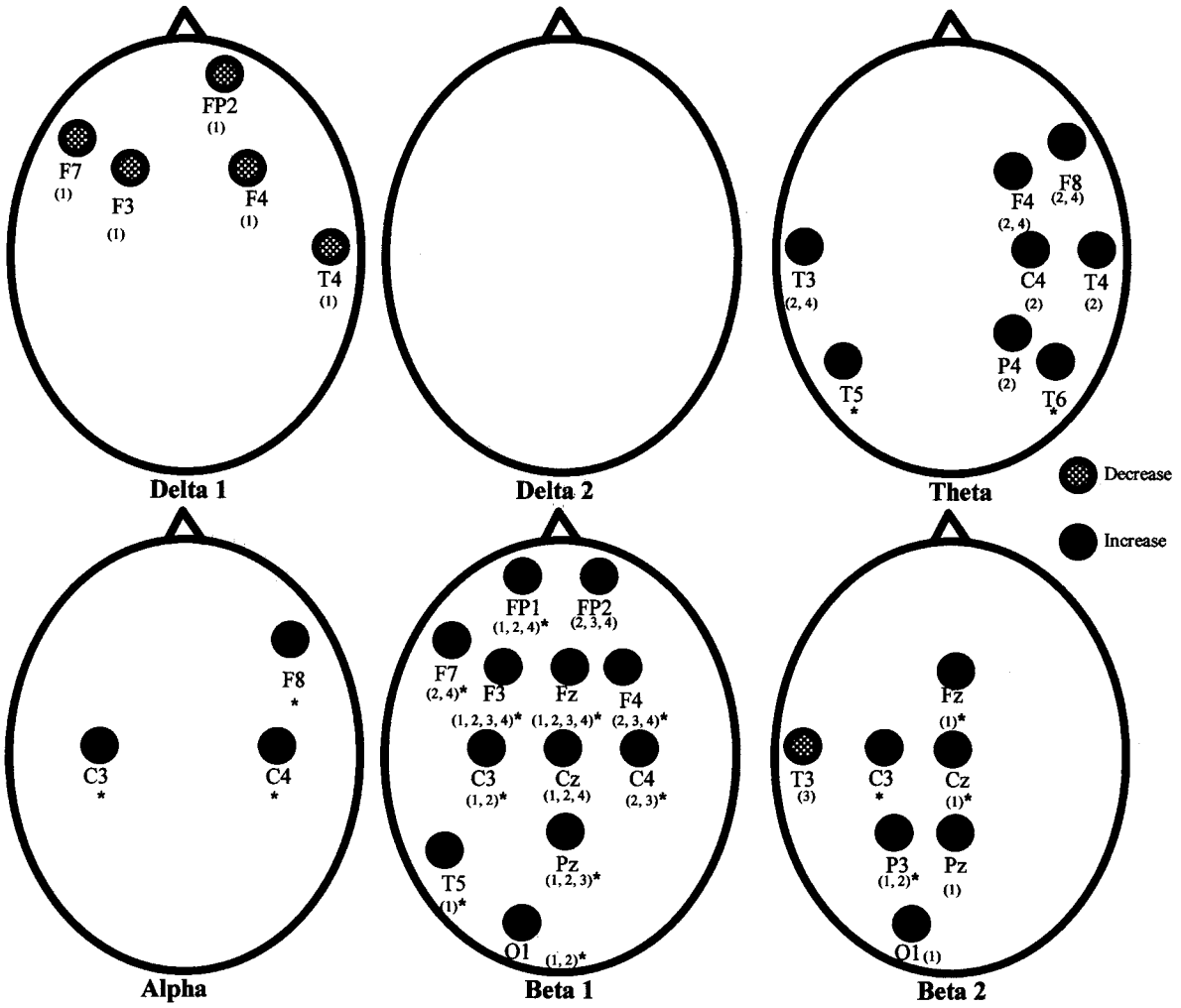

Fig. 2. Significant changes from baseline EEG activity during the beta AVS condition. Numbers indicate time period of significance (1 = first 5 min of AVS, 2 = second 5 min, 3 = third 5 min, 4 = last 5 min). Asterisks indicate significant changes remaining 20 min after the AVS session had ended. Correction for multiple comparisons: Bonferroni.

post-session increases in power from baseline levels can be explained as alpha blocking by a visual stimulus. Finally, our findings indicated different patterns of significant increases and decreases in response to alpha and beta stimulation, respectively, using the same participants for both conditions. If these results were due to the arousing effects of sensory stimulation alone, and not specific to the AVS frequency presented, we would expect similar patterns of increases and decreases for both conditions.

A possible explanation for these data can be found in Dieter and Weinstein's report of the subjective states experienced during low-frequency AVS. They state that 'as photo-stimulation progresses, the individual experiences a free-flowing chain of thoughts... which is followed by dynamic visual patterns' (Dieter and Weinstein, 1995, p. 87). They suggest that participants enter a hypnagogic state similar to Stage 1 of the NREM sleep stages. In the current study, the increases in power in the delta and theta bandpasses within the AVS sessions may be attributed to the increased visual imagery and relaxation

experienced during AVS reported by our participants. Increases in the beta bandpasses may be associated with the active flow of thought most participants said occurred during AVS. It remains to be explained why participants would continue to have significantly more power in beta 1 after alpha AVS, and significantly more power in the theta, alpha, beta 1 and beta 2 bandpasses after beta AVS, 30 min after the AVS sessions had ended.

These preliminary data are presented to provide researchers interested in the affects of AVS on the cortical EEG and which additional locations and bandpasses to consider in future analyses. A control measure should be incorporated in future studies. Although unlikely, it is possible the persistent increase in power within beta 1 for both alpha and beta AVS could be due to merely sitting quietly with eyes closed for 20 min.

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References

Adrian, E.D., Matthews, B.H.C., 1934. The Berger rhythm: potential changes from the occipital lobes in man. Brain 57, 355–384.

Anderson, D.J., 1989. The treatment of migraine with variable frequency photostimulation. Headache 29, 154–155.

Brauchli, P., Michel, C.M., Zeier, H., 1995. Electrocortical, autonomic, and subjective responses to rhythmic audio-visual stimulation. Int. J. Psychophysiol. 19, 53–66.

Carter, J.L., Russell, H.L., 1993. A pilot investigation of auditory and visual entrainment of brainwave activity in learning-disabled boys. Texas Res.: J. Texas Center Educat. Res. 4, 65–73.

Dieter, J.N.I., Weinstein, J.A., 1995. The effects of variable frequency photo-stimulation goggles on EEG and subjective conscious state. J. Ment. Imag. 19, 77–90.

Kawaguchi, T., Jijiwa, H., Watanabe, S., 1993. The dynamics of phase relationships of alpha waves during photic driving. Electroencephalogr. Clin. Neurophysiol. 87, 88–96.

Montgomery, D.D., Ashley, E., Burns, W.J., Russell, H.L., 1994. Clinical outcome of a single case study of EEG entrainment for closed head injury. Proc. Assoc. Appl. Psychophysiol. Biofeedback 25, 82–83.

Morse, D.R., 1993. Brain wave synchronizers: a review of their stress reduction effects and clinical studies assessed by questionnaire, galvanic skin resistance, pulse rate, saliva, and electroencephalograph. Stress Med. 9, 111–126.

Patrick, G.J., 1996. Improved neuronal regulation in ADHD: an application of 15 sessions of photic-driven EEG neurotherapy. J. Neurother. 1, 27–36.

Pigeau, R.A., Frame, A.M., 1992. Steady-state visual evoked responses in high and low alpha subjects. Electroencephalogr. Clin. Neurophysiol. 84, 101–109.

Rosenfeld, J.P., Reinhart, A.M., Srivastava, S., 1997. The effects of alpha (10 Hz) and beta (22 Hz) 'entrainment' stimulation on the alpha and beta EEG bands: individual differences are critical to prediction of effects. Appl. Psychophysiol. Biofeedback 22, 3–20.

Russell, H.L., 1997. Intellectual, auditory and photic stimulation changes in functioning in children and adults. Biofeedback 25, 16–17.

Solomon, G.D., 1985. Slow wave photic stimulation in the treatment of headache — a preliminary study. Headache 25, 444–446.

Townsend, R.E., Lubin, A., Naitoh, P., 1975. Stabilization of alpha frequency by sinusoidally modulated light. Electroencephalogr. Clin. Neurophysiol. 39, 515–518.

Walter, V.J., Walter, W.G., 1949. The central effects of rhythmic sensory stimulation. Electroencephalogr. Clin. Neurophysiol. 1, 57–86.